



# **An Equivalent Circuit Model of a Novel Photodetector**

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# An Equivalent Circuit Model of a Novel Photodetector

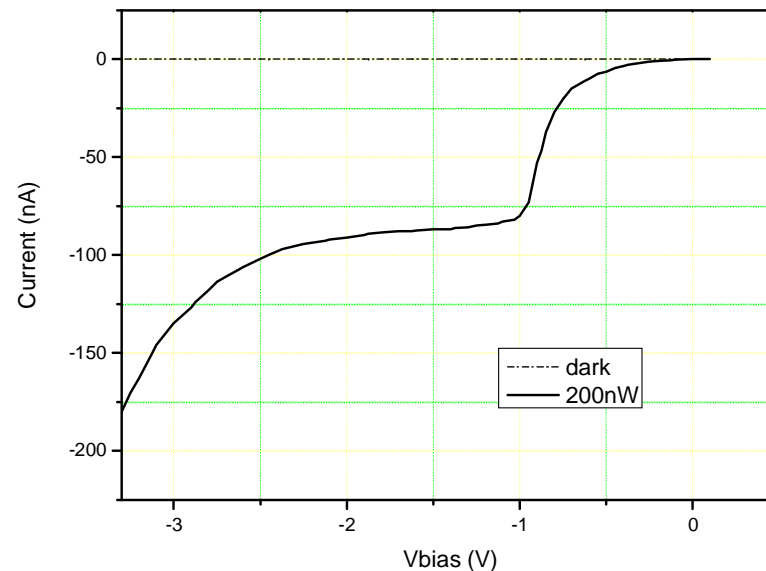
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## Overview

- ❑ Building up equivalent circuit model of photoelectric device is quite necessary before design the readout circuit.
- ❑ The equivalent circuit model is presented by combination with the result of curve fitting, and simulated with Cadence EDA platform.
- ❑ The circuit model could be optimized and could be linked with the readout circuit.
- ❑ The signification of the equivalent circuit model may be design an optimal readout circuit for the novel PD.

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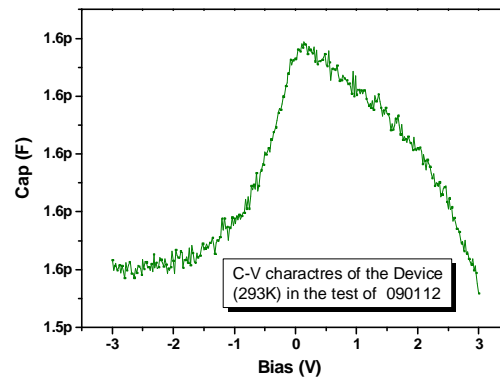
## Characterizing of the photodetector



- The electric current vs voltage (I-V) curve of near infrared low dimension photodetector was gained by the Keithly 4200-SCS at  $1.3\mu\text{m}$  photo source and room temperature.
- The range of bias voltage is from -4V to 0V and the voltage step 0.02V.

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## Characterizing of the photodetector



- ❑ The C-V curve was measured by a DC bias voltage and a small-signal AC bias voltage added at same time.
- ❑ The range of the bias voltage was from  $-3V \sim +3V$ , the voltage step  $0.02V$  and the  $1MHz$  frequency at room temperature.

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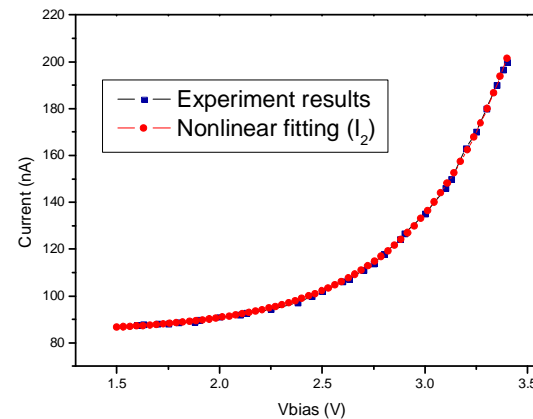
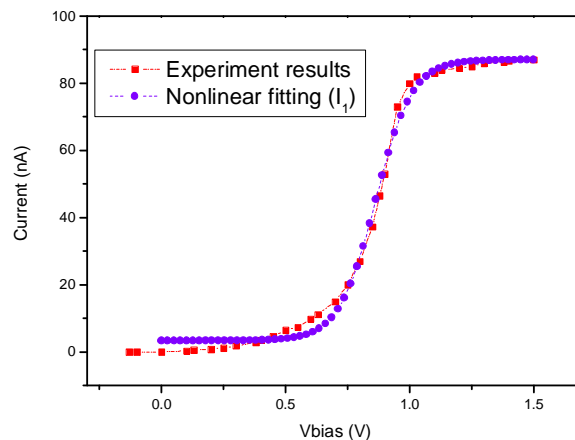
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## Curve fitting

- ❑ Nonlinear fitting of I-V curve is completed by applying Origin software.
- ❑ Curve fitting includes full fitting and sectional fitting.
- ❑ The result of full fitting can be applied to circuit modeling directly. The sectional fitting is suitable for special curve and it is more accurate.

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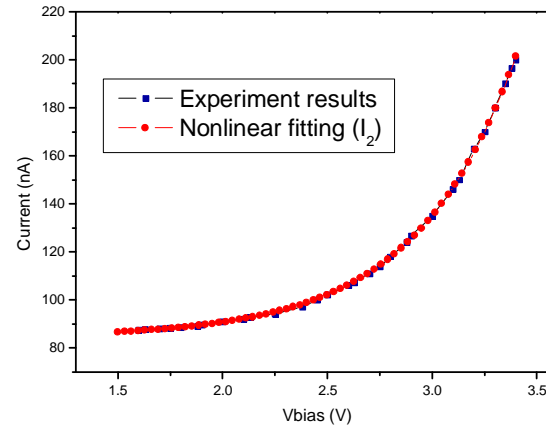
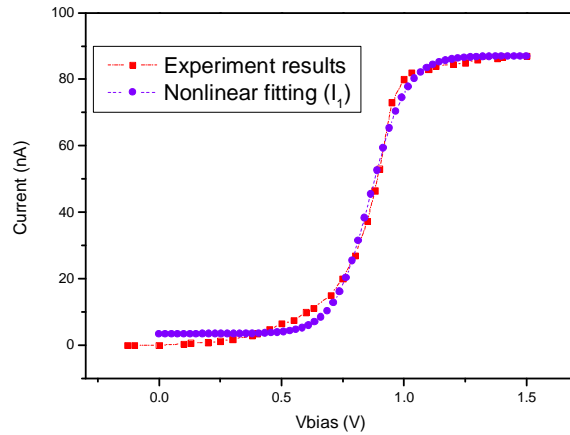
## Curve fitting



- The curves is divided into two sections at  $V_{\text{bias}}=1.5\text{V}$ , on the flat parts of the curve.
- Because the I-V curve shows exponential function relation, the fitting need change the direction of coordinate (abscissa and ordinate).

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## Curve fitting

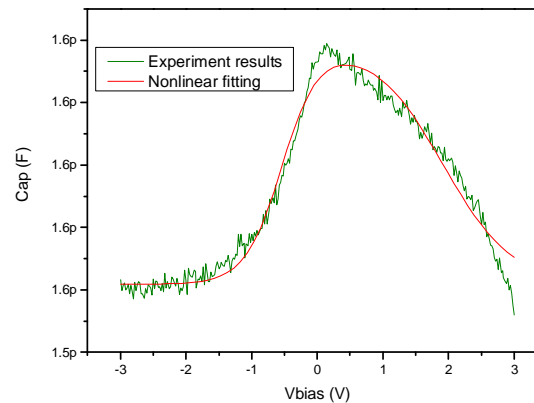


- Left Fig. shows the nonlinear fitting curve and experimental curve at  $V_{bias}$  range  $[0, 1.5]$ .
- Right Fig. shows the curves at  $V_{bias}$  range  $[1.5, 3.5]$ .
- The result of sectional fitting is given by:

$$\begin{cases} I_1 = 86.97 + \frac{3.35 - 86.97}{1 + e^{(V - 0.86) / 0.07}} \text{ (nA)} & V \in [0 \quad 1.5] \quad (1) \\ I_2 = 84.44 + 5.46 \times e^{(V - 1.94) / 0.47} \text{ (nA)} & V \in [1.5 \quad 3.5] \quad (2) \end{cases}$$

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## Curve fitting



- ❑ The Fig. shows the nonlinear fitting curve and experimental curve for PD C-V.
- ❑ The intrinsic capacitance of the novel PD is composed of depletion capacitance and storage capacitance.
- ❑ In the optical radiation condition, the polarization effect of photo-generated carriers affects the intrinsic capacitance of the PD.
- ❑ The full fitting is suitable for C-V curve fitting.

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## Curve fitting

- The result of full fitting is given by:

$$C_p = 1.56 + \frac{7.69}{1 + e^{-(V-0.69+1.22)/0.28}} \\ \times \left(1 - \frac{1}{1 + e^{-(V-0.69-1.22)/0.52}}\right) \quad (pF)$$

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## Equivalent circuit modeling

- According to the result of I-V curve fitting above, the equivalent circuit model needs two voltage controlled current sources.
- A switching function is needed at the dividing point of the 1.5V, it can be achieved by the integral.
- The function can be expressed as follows:

$$K(V) = \text{int}\left(\frac{V - 1.5}{V - 1.5 - \delta}\right) \quad 0 < \delta \ll 1$$

- The K (V) is given by

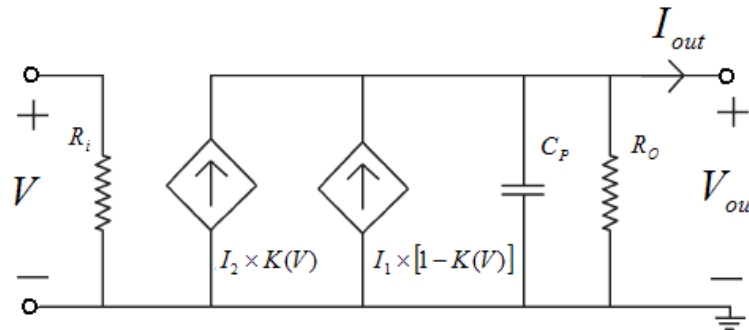
$$K(V) = \begin{cases} 0 & V \in [0 \quad 1.5] \\ 1 & V \in [1.5 \quad 3.5] \end{cases}$$

Where V is the bias voltage of the PD and  $\delta$  a constant.

# An Equivalent Circuit Model of a Novel Photodetector

## Equivalent circuit modeling

- According to the curve fitting of I-V and C-V, the equivalent circuit model is shown:



- Where  $C_p$  the intrinsic capacitance;  $R_o$ ,  $R_i$  the resistances;
- The current of PD severally at different range of bias voltage:

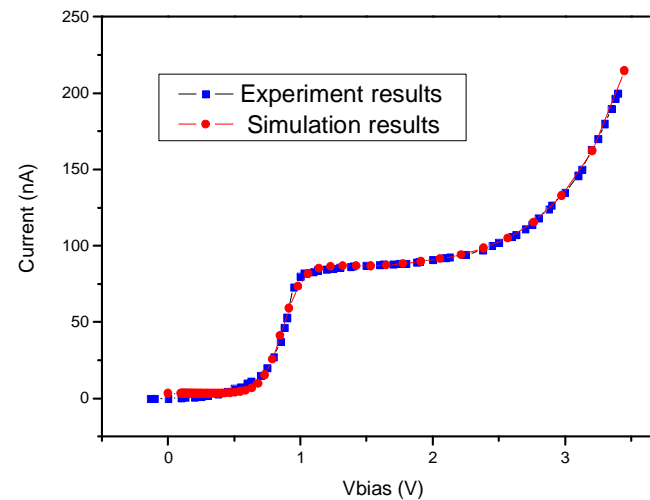
$$I_1 \times [1 - K(V)], I_2 \times K(V)$$

- The  $R_o$  is an important parameter, it can be calculated from C-F curve.
- The parameters  $C_p$ ,  $R_o$  and  $K(V)$  are all the functions of bias voltage  $V$ .

# An Equivalent Circuit Model of a Novel Photodetector

## Simulation results

- The signification of this equivalent circuit model is to design an optimal readout circuit for the PD.



- The Fig. shows the simulation results of equivalent circuit model with Cadence EDA platform, which is consistent with the experiment data.
- It can be used as the signal source of readout circuit and matching with readout structure.

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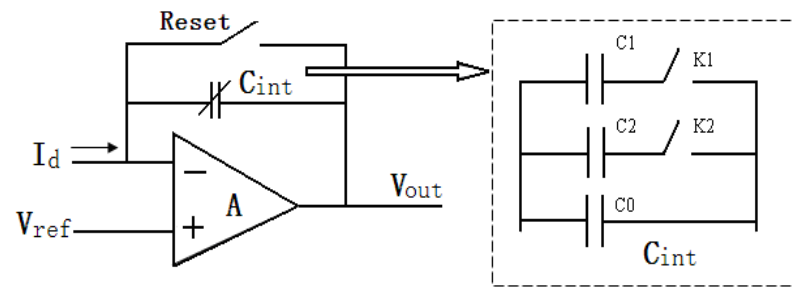
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## Readout Design

- The capacitor feedback transimpedance amplifier (CTIA) of the transition current to voltage used amplifying small signal is implemented by means of a low-noise preamplifier and a feedback capacitor.
- Based on the principle of charge conservation, the equation can be given by
$$C_{\text{int}} \times \Delta V = I_d \times T_{\text{int}}$$
- Here,  $T_{\text{int}}$  is the feedback capacitor,  $\Delta V$  output voltage range,  $I_d$  PD current.
- $T_{\text{int}}$  adjusts integration time for realizing CTIA performance.

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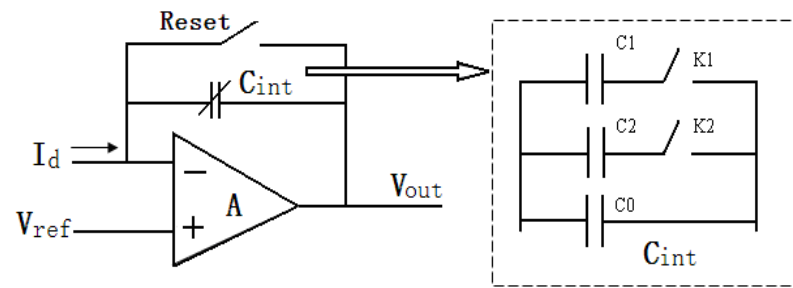
## Readout Design



- ❑ Because the novel PD has an I-V sudden change, a certain feedback capacitor is not suitable for large changes of current level.
- ❑ The method of turning  $C_{int}$  is proposed. The Fig. shows the design of optimal readout structure.
- ❑ Where,  $V_{ref}$  is reference voltage, Reset for reset switch of CTIA.

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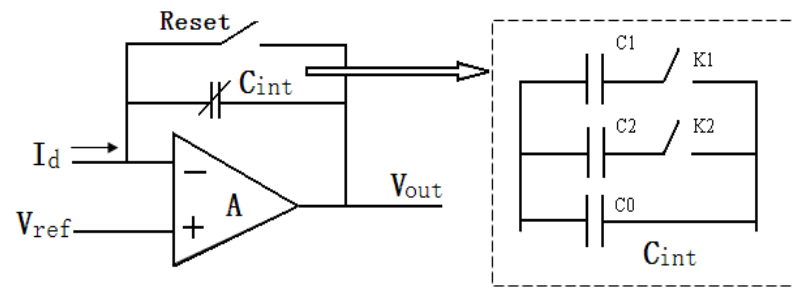
## Readout Design



- ❑ The  $C_{int}$  is divided into three parts  $C_0$ ,  $C_1$  and  $C_2$ .
- ❑ The value of  $C_0$ ,  $C_1$ ,  $C_2$  is each 1pF, 1pF, 2pF.
- ❑ Moreover,  $C_1$  and  $C_2$  are in series with switches  $K_1$  and  $K_2$  respectively. When the switch is 0, the switch off, otherwise is on state.

# An Equivalent Circuit Model of a Novel Photodetector

## Readout Design



- ❑ When  $V_{bias}$  range in 0-1.5V,  $C_0$  is suitable.
- ❑ When  $V_{bias}$  range in 1.5-3.5V,  $C_1$  or  $C_2$  should be in parallel with  $C_0$ , and increase the value of the feedback capacitor.
- ❑ The states  $K_1$  and  $K_2$  could make different CTIA performances.

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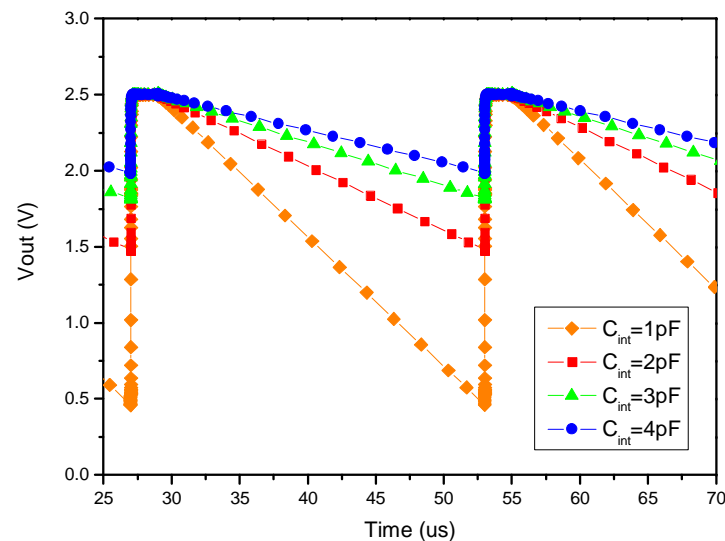
## Readout Design

K2	K1	$C_{int}$ (pF)	$T_{int}=24\mu s, I_{max}$ (nA)	Output voltage range $\Delta V$ (V)
0	0	1	85	2
0	1	2	170	2
1	0	3	255	2
1	1	4	340	2

- The Table shows: according to the I-V curve of the novel PD,  $K_1$  and  $K_2$  will be set in different state, while the bias voltage is set at different voltage range.

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## Readout Design



- The Fig. shows the simulation result of CTIA with different value of  $C_{int}$ .
- The CTIA can export optimal voltage level.

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## Summary

- ❑ An equivalent circuit model of a novel photoelectric detector has obtained by setting appropriate circuit parameters.
- ❑ The curve fitting was not only associating the bias voltage and the current (I-V), but also relating the bias voltage and the capacitance (C-V) of the PD.
- ❑ The accuracy of the model could be verified by simulating the circuit.
- ❑ The simulation results are in agreement with the experimental results.
- ❑ At last, a matched readout circuit structure based on the circuit model is designed and well readout the practicable response signal.



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***Thanks for your attention!***